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RELATION OF TRANSPIRATION TO GROWTH IN WHEAT.

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY. LXXVII.

BURTON EDWARD LIVINGSTON.

(WITH TWENTY-ONE FIGURES)

INTRODUCTION.

TRANSPIRATION being a continuous phenomenon in living plants, and being at the same time readily measurable, it has been suggested by WHITNEY and CAMERON[1] that here is a criterion for comparing the rates of growth of similar cultures made in different media. It was found at the start that when two cultures of wheat seedlings were prepared, exactly alike except that one was in a good soil and another in a poor, the total transpiration for a period of ten days or more was invariably much greater in the former culture, the difference between the two amounts of water lost being roughly equivalent to the difference between the agricultural values of the soils. It was deemed worth while to investigate this fact more carefully, and the present paper embodies the results of such investigations.

The Russian variety of wheat known as "chul" was used in these experiments. The soil cultures were grown in wire baskets covered with paraffin, such as those described in the paper cited above. For any one series the initial moisture content of all the soils was the same, being about the optimum for plant growth under the conditions of the experiment. The transpiration was determined daily, or at intervals of four days or less, by the method of weighing; and the necessary amount of water was then added to bring the soil back to its original moisture content. The baskets of any series stood side by side in a plant house, being thus subjected to exactly the same changes in temperature, humidity, light, and air currents. Six wheat seedlings were grown in a basket.

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[1] WHITNEY, M. and CAMERON, F. K. Investigations in soil fertility. U. S. Department of Agriculture, Bureau of Soils, Bull. 23. 1904.

Water cultures were grown in black bottles of about 50^{cc} capacity, the seedlings being first germinated in sand and then placed in cork stoppers in the manner described by the authors just referred to. Transpiration was taken by weighing, and the solutions were changed every few days. Otherwise, these were grown under the same conditions as were the basket cultures. Four wheat seedlings were grown in a bottle.

At the end of an experiment the series was photographed, the tops were removed by cutting just above the seeds, the leaf surface was determined, and also the weight of tops and leaves. The determination of leaf surface was made in the following way, which is a modification of that used by previous writers.[2] A plate of glass was coated with dextrin mucilage and the latter allowed to become nearly dry. On this was gummed the wheat leaves side by side, with their edges in contact so far as possible. When the mucilage had become thoroughly dry, but before the leaves had dried appreciably, a photographic print of the leaf outline was made by direct contact. For this the developing paper called "velox" was used; after being developed, fixed, and washed the sheets were squeegeed and dried on ferrotype plates, face down, thus giving perfectly smooth, hard surfaces. The white area of a print so prepared is equal to the area of one side of the leaves whose surface is to be determined. This area was measured by one of two methods, which were found to agree accurately: (1) it was measured directly by means of a planimeter; (2) its area was obtained indirectly by cutting around its margins with scissors and then weighing the white portion as well as the whole sheet. The area of the entire sheet having been first obtained from its dimensions, the required area of the white portion is easily obtained from the known quantities by calculation, assuming that the paper is uniform. The two weights were both obtained at the same time after cutting out the white portion, in order to avoid any errors due to changes in the moisture content of the paper. The uniformity of the latter was tested as follows: four rectangular pieces of velox paper were developed, fixed, washed, and dried as in the actual determination of leaf area. From each of these was determined, by weighing and measurement, the weight of $1^{sq\ cm}$ of paper. The results are tabulated below:

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[2] BURGERSTEIN, A., Die Transpiration der Pflanzen. Jena. 1904. Pp. 24, *et seq.*, and the references there made.

	Area, sq cm	Weight. gr.	Average weight of 1sq cm
Sheet A........	229.852	3.642	0.01584
Sheet B..........	109.650	1.772	0.01616
Sheet C........	70.992	1.098	0.01547
Sheet D........	49.210	0.771	0.01565

Average weight of $1^{sq\ cm}$, by all tests, 0.01573; greatest variation from average, 0.00043; greatest variation from average in per cent. of average, 2.7 per cent.

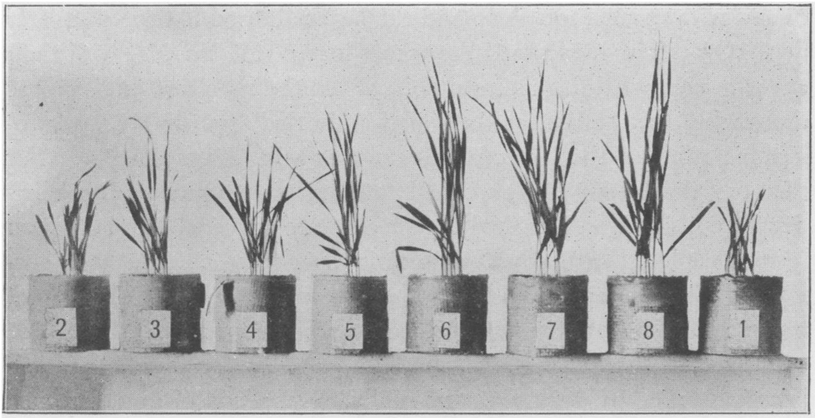

FIG. 1

From these figures and other similar ones it appears that this paper so treated is uniform within 3 per cent. of error. Since the planimeter method gives approximately the same results as that by weighing, the two methods can be used interchangeably. The former is the more direct and consumes less time and energy, so that where the instrument is at hand it should be used for this sort of work.

In both soil and water cultures a number of duplicates were often carried through so far as transpiration was concerned. In such cases, owing to the great amount of work involved, the other measurements were made for only one series and not for the duplicates.

The experiments, results of which are recorded in the present paper, were carried out in the laboratories of the Bureau of Soils of the United States Department of Agriculture, Washington, D. C. I am indebted to Professor MILTON WHITNEY, to Dr. F. K. CAMERON, and to all the members of the laboratory staff for facilities and assistance without which the work could not have been done. Especially am I indebted to Mr. FRANK D. GARDNER, in charge of the Division of Soil Management, for cultures from which a number of the series were obtained, and for the data themselves in case of Series IV to X inclusive.

EXPERIMENTS.

The cultures will be described in the following paragraphs. It is to be remembered that for any single series the only environmental factors which were varied are those connected with the nature of the medium in which the roots were growing. The criteria for comparing the growth of the different cultures of a series are (1) total transpiration during the period of the experiment, (2) green weight of tops and (3) of leaves, and (4) area of leaves. In these studies aerial growth alone is considered, the investigations into the growth of roots being reserved for another paper.

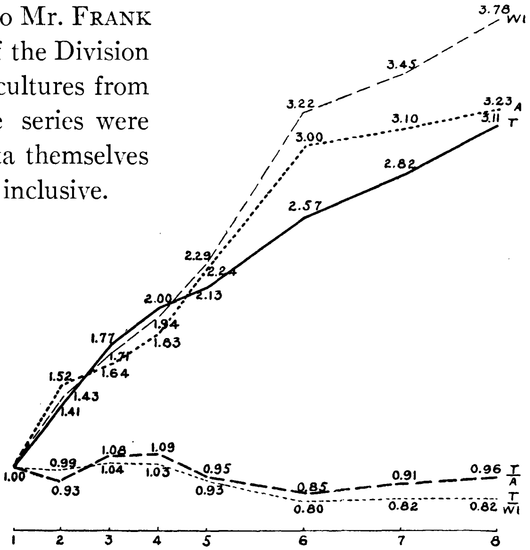

FIG. 2

Series I.—A very poor natural soil from Takoma Park, Md., was used in this series. Basket no. 1 contained the natural soil and the others the same soil mixed with fermented stable manure in different amounts. The plants were weighed at intervals of from one to three days. The experiment lasted from October 25 to November 11, 1904. A photograph of the series at the end of the experiment is shown in *fig. 1.* Data for the series are given in the following table. The baskets are arranged according to the total transpiration for the period of the experiment.

These data are best presented in the form of curves (*fig. 2*).

DATA FOR SERIES I.

Treatment	No. of basket	Total transp. (T)[4]	Leaf area (A)[5]	Green wt. of leaves $(Wl.)$[6]	$\frac{T}{A}$[7]	$\frac{T}{Wl.}$[8]
Takoma soil	1	29.7	27.657	0.51	1.07	58.2
" + 5000 p. p. m.[3] manure	2	41.9	42.182	0.73	0.99	57.4
" + 10000 " "	3	52.6	45.392	0.87	1.16	60.4
" + 15000 " "	4	59.5	50.658	0.99	1.17	60.1
" + 20000 " "	5	63.4	62.304	1.165	1.02	54.2
" + 30000 " "	6	76.2	83.207	1.635	0.91	46.4
" + 40000 " "	7	83.7	85.982	1.760	0.97	47.5
" + 50000 " "	8	92.4	89.372	1.930	1.03	47.9

Abscissas are here taken proportional to the amounts of manure in the different baskets, and a curve is drawn for each column of figures in the table, these being first reduced so as to be mutually comparable by calculating each quantity in terms of that for basket no. 1, considered as unity. The numbers so obtained are plotted as ordinates for their respective curves. Thus the curves all start at the same point and their nearness to coïncidence or parallelism is the criterion for judging whether or not the different sets of measurements vary in the same order. The derived numbers, from which the curves are plotted, are placed upon them and need not be tabulated. The basket numbers (which correspond to the treatments, see the table) are placed below the curves in a horizontal line. A symbol corresponding to a column in the table is placed at the right of each curve and designates the particular set of data for which it is drawn. Thus, T is the curve of transpiration, A of leaf area, Wl of leaf weight, $\frac{T}{A}$ transpiration per $2^{\text{sq cm}}$ of total leaf area, and $\frac{T}{Wl}$ transpiration per gram of green leaves.

It is seen immediately that the curves for transpiration, leaf weight, and leaf area all lie quite close to one another. Judging the relative growth of the different cultures by any one of these three curves results in arranging the baskets in identically the same series, which is likewise the series obtained by arranging them in accordance with the amount of manure added.

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[3] p. p. m. will be used throughout to denote parts per million, by weight.

[4] The transpiration figures are always in grams.

[5] Leaf area is given for only one side of the leaves, always in square centimeters.

[6] In grams.

[7] Transpiration per $2^{\text{sq cm}}$ of total leaf area.

[8] Transpiration per gram of green leaves.

The two remaining curves indicate that both transpiration per

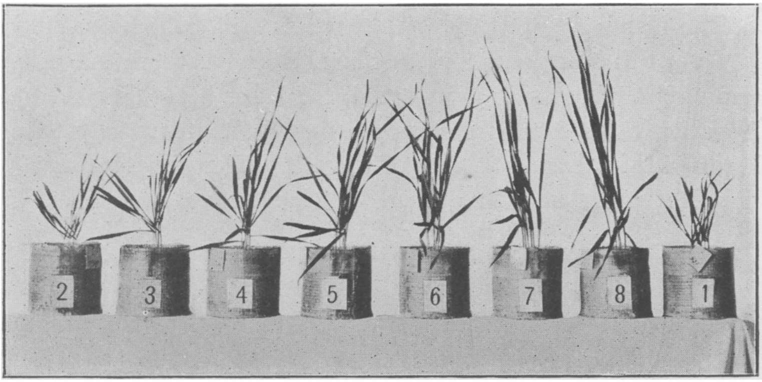

FIG. 3

unit area of the leaves and transpiration per gram of their green weight are practically uniform throughout the series; their curves are nearly horizontal lines. Of course this uniformity is due to the nearness to coincidence of the other three curves and is a criterion for judging of the latter property. There appears to be a very slight tendency for the transpiration per square centimeter to be depressed in the better soils, and a somewhat more marked, but still slight, tendency for the other ratio to be depressed in the same way.

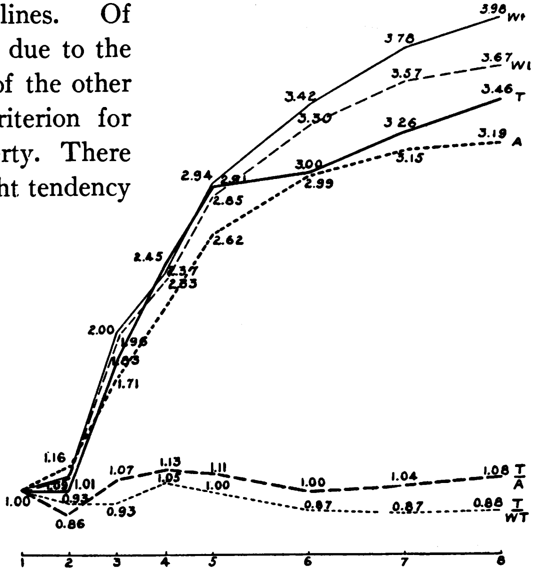

FIG. 4

In the following descriptions of series, the tables of observed data will often be omitted, the numbers placed upon the curves showing their relative magnitudes, which alone are of interest here.

Series II.—This series is identical in treatment with Series I. It lasted 18 days, from November 11 to November 29, 1904.

The plants are shown in *fig. 3*, and curves for the series are given in *fig. 4*. It will be noticed that in this case both weight of leaves and weight of tops are represented, the latter being denoted by *Wt.* Apparently the former increases somewhat more rapidly than the latter with increasing fertility of the soil. The curves of transpiration, leaf area, and the other two curves just mentioned lie so close together that according to any one of them the several baskets would fall into exactly the same series, which would again be identical with that obtained by arranging them in accordance with the increasing amounts of manure used. Transpiration per unit area is fairly uniform throughout this series, but that per gram of green tops decreases slightly with increasing fertility. The series is on the whole in harmony with Series I.

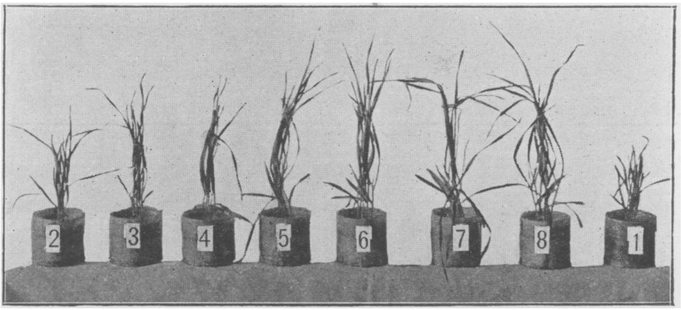

FIG. 5

Series III.—This series is another duplicate of Series I. The experiment lasted from November 23 to December 14, 1904. The plants are shown in *fig. 5*, and *fig. 6* represents the curves. If basket no. 2 were omitted from the series (and it is obvious that its data are very erratic, though wherein the error lies it is impossible to determine), the curves would take the general form as those of Series I and II. It is again seen that the order of arrangement of the baskets by amount of transpiration agrees with that obtained from the relative amounts of manure, leaf area, and weights of leaves and of tops. Here the two lower curves are again nearly horizontal lines. There is a slight tendency for transpiration per unit area to increase with increasing soil fertility, but this tendency is hardly shown at all in case of transpiration per gram.

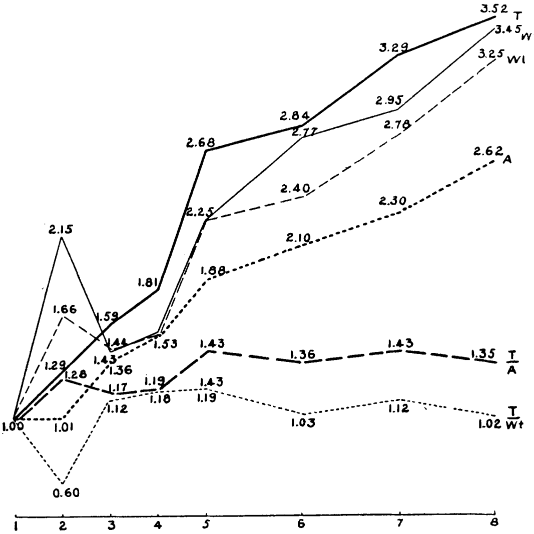

FIG. 6

Series IV, V, and VI.—These are duplicates of I, II, and III respectively, carried on at the same time and in the same place. While the three already described are based on a single basket of each treatment, those here presented are based on four baskets, containing in all twenty-four plants. Only transpiration and green weight of tops are considered; the other determinations were not made here.

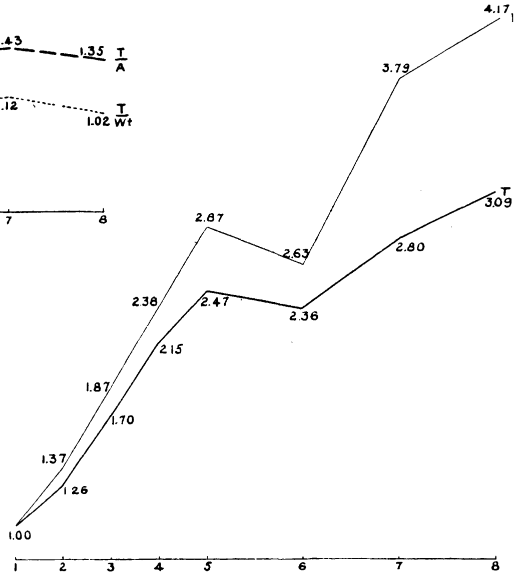

FIG. 7

Curves for these three series are given in *figs. 7, 8,* and *9*. In *fig. 7* it is to be noted that culture 6, containing 30,000 p.p.m. manure in the Takoma soil, shows a discrepancy which was not found in Series I, of which this is a duplicate. No reason for this can be given. It is obviously due, however, to soil conditions, since the curve of transpiration follows closely that of weight, both exhibiting the same drop for culture 6.

There are no discrepancies in Series V; the curves of *fig. 8* approximate each other throughout and agree very well with those of Series II.

Series VI (*fig. 9*) shows a fall in transpiration in culture 3, which does not occur in Series III. This fall in transpiration is accompanied by a very much diminished relative weight, although this does not amount to an actual depression in the curve. Aside from this culture the series is in agreement with the preceding, and the two curves are seen to be very closely similar throughout.

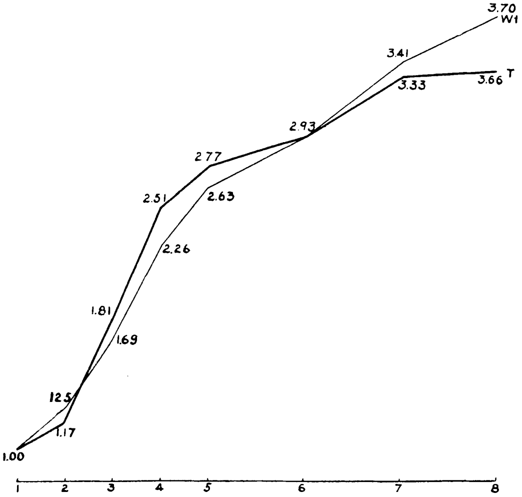

FIG. 8

For the six similar series so far described, it appears that total transpiration is as good a criterion as green weight for judging of the relative growth in these soils. The differences are generally somewhat more marked by the weight criterion than by that of transpiration. Series III is an exception to this, however.

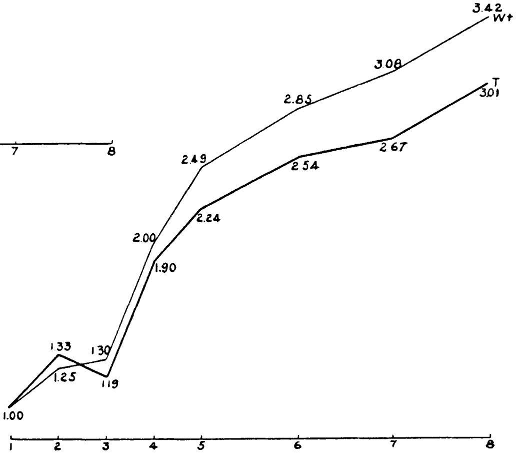

FIG. 9

Series VII.—This series consists of Cecil clay[9] poor with various treatments as given in the following table. The samples which received fertilizers were mixed with the latter, moistened, and allowed to stand several weeks with frequent stirring. The aerated soil was treated in the same way. At the end of this time lime was added to certain of the samples and the seeds were then planted. The proportions of fertilizers added are stated under "treatment" in the following table. Where more than one fertilizer was used, each was in the same proportion as when used alone. The amount of lime added is given in the third column. Five baskets of six plants each were used for each treatment. The experiment lasted from November 19 to December 8, 1904. The data are given in the following table. Only transpiration and weight are given. The cultures are arranged in order of transpiration figures.

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[9] This soil is from near Statesville, N. C. It is a stiff reddish clay, considered the best soil of the Piedmont Plateau for general farming purposes. The good and poor varieties are markedly different agriculturally, but appear to be identical so far as soil analysis can determine.

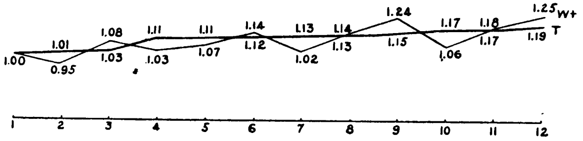

FIG. 10

DATA FOR SERIES VII

Treatment	Culture no.	P.p.m. lime added	Green weight of tops (*Wt*)	Total transpiration (*T*)
Cecil clay good added to poor	1	4000	7.30	313.8
10 per cent. Cecil clay poor, aerated	2	none	6.95	316.5
$NaNO_3$. 127 p.p.m.	3	2000	7.85	324.2
Lime. 1000 p.p.m.	4	none	7.50	337.5
$Ca_3(PO_4)_2$. 77 p.p.m.	5	2000	7.50[10]	348.4[10]
$NaNO_3+Ca_3(PO_4)_2$	6	3000	8.35	351.1
Stable manure. 7000 p.p.m.	7	2000	7.50	353.7
K_2SO_4. 130 p.p.m.	8	2000	8.35	356.1
$NaNO_3+K_2SO_4+Ca_3(PO_4)_2$	9	3000	9.05	361.3
Cecil clay poor, natural	10	none	7.75	367.0
KNO_3. 151 p.p.m	11	4000	8.65	368.0
$NaNO_3+K_2SO_4$	12	3000	9.10	372.9

The curves are shown in *fig. 10*. That of transpiration is practically a straight line and is nearly horizontal. The weight curve varies on both sides of that of transpiration, leaving the latter as approximately the mean of the points of the former. No marked improvement of the soil by any of the treatments used is to be made out. All variations here are comparatively very slight.

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[10] Only 29 plants; calculated numbers for 30 plants are: *Wt*, 7.80; *T*, 349.2.

Series VIII.—This is a series similar to the last described, and carried out at the same time, but having as its basis another natural soil, Leonardtown loam poor.[11] For the treatments and data see the following table, in which the system of notation is the same as in the last. The cultures are again arranged by transpiration figures.

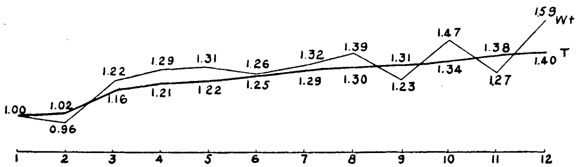

FIG. 11

Curves for these data are given in *fig. 11*. They agree very well in all points with the last series discussed.

Series IX.—This again is similar to Series VII, and was carried out at the same time, but is made from Leonardtown loam good, and sodium nitrate was added at the time of planting in place of lime, as in the last two series. The system of notation is the same as above and the cultures are arranged as in the two preceding series.

DATA FOR SERIES VIII

Treatment	Culture no.	P.p.m. lime added	Green weight of tops (*Wt*)	Total transpiration (*T*)
Leonardtown loam poor, aerated	1	none	6.05	276.2
Leonardtown loam poor, natural	2	none	5.80	280.8
$Ca_3(PO_4)_2$. 77 p. p. m	3	2000	7.40	320.4
$NaNO_3+Ca_3(PO_4)_2$	4	3000	7.80	333.0
K_2SO_4. 130 p. p. m	5	2000	7.90	337.3
10 per cent. Leonardtown loam, good added to poor	6	4000	7.60	347.5
$NaNO_3$. 127 p. p. m	7	2000	8.00	356.4
KNO_3. 151 p. p. m	8	4000	8.40	359.5
Lime. 1000 p. p. m	9	none	7.45	362.0
$NaNO_3+K_2SO_4$	10	3000	8.90	371.1
Stable manure. 7000 p. p. m	11	2000	7.70	428.0
$NaNO_3K_2SO_4+Ca_3(PO_4)_2$	12	3000	9.55	387.7

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[11] This soil was collected near Leonardtown, Md. It is a yellow silty loam, closely resembling loess, and is considered a good soil for general farming. It occupies arge areas in Maryland and Virginia, and to some extent in Kentucky. The good and poor varieties of this soil are related in the same manner as those of Cecil clay.

DATA FOR SERIES IX

Treatment	Culture no.	P.p.m. $NaNO_3$ added	Green weight of tops (*Wt*)	Total transpiration (*T*)
10 per cent. Leonardtown loam poor added to good	1	765	8.80	323.0
Leonardtown loam good, natural	2	none	7.40[12]	352.8[12]
KNO_3. 151 p. p. m	3	606[13]	10.10	375.6
$NaNO_3+K_2SO_4+Ca_3(PO_4)_2$	4	382	11.00	384.6
$NaNO_3+K_2SO_4$	5	none	10.50	398.6
Manure. 7000 p. p. m	6	637	11.70	402.1
$Ca_3(PO_4)_2$. 77 p. p. m	7	382	10.40	406.1[14]
Lime. 1000 p. p. m	8	510	10.70[14]	410.0
$NaNO_3+K_2SO_4$	9	none	10.20	424.1
K_2SO_4. 130 p. p. m	10	255	10.05	426.9
Leonardtown loam good, aerated	11	none	9.90	438.0
$NaNO_3$. 127 p. p. m	12	none	10.60	438.4

The curves are given in *fig. 12*. With the exception of culture 2, and perhaps also of the last three cultures of the series, in which weight is low as compared to transpiration, these agree with the last two series discussed.

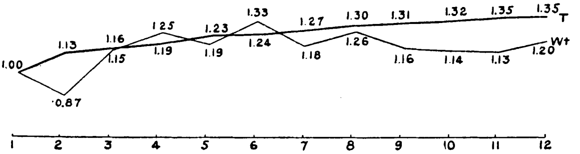

FIG. 12

Series X.—This consists of five different natural soils and a rich garden soil from the greenhouse. The experiment lasted thirty-four days, from November 11 to December 15, 1904. Weight of both leaves and tops as well as transpiration and leaf area were determined. A single basket of six plants was used for each soil. The data are given in the table. The arrangement is by transpiration figures.

DATA FOR SERIES X.

Soil	Basket no.	Total transpiration (*T*)	Leaf area (*A*)	Green weight leaves (*Wl*)	Green weight of tops (*Wt*)	$\frac{T}{A}$	$\frac{T}{Wt}$
Cecil clay poor	1	68.8	48.1	0.70	0.86	1.43	80.1
Takoma soil	2	70.6	48.8	0.73	0.73	0.86	82.1
Leonardtown loam poor	3	90.1	60.6	0.97	1.21	1.49	74.5
Cecil clay good	4	90.1	63.8	1.02	1.28	1.41	70.4
Leonardtown loam good	5	127.9	74.8	1.24	1.54	1.71	83.1
Garden soil	6	148.6	95.4	1.54	2.11	1.56	70.4

[12] Only 29 plants; calculated numbers for 30 plants are: *Wt*, 7.65; *T*, 365.1.

[13] KNO_3 in place of $NaNO_3$.

[14] Only 29 plants; calculated numbers for 30 plants are: *Wt*, 11.10; *T*, 420.0.

The plants are shown in *fig. 13*, and the curves in *fig. 14*. Those for weight, transpiration, and leaf area approximate each other very well. With increasing fertility of the soil the transpiration increases somewhat more rapidly than the area, while the same function increases somewhat less rapidly than the weight of tops. Thus the curve of transpiration per unit area rises slightly, while that for transpiration per gram falls to about the same degree. The last two curves, however, both approximate horizontal straight lines.

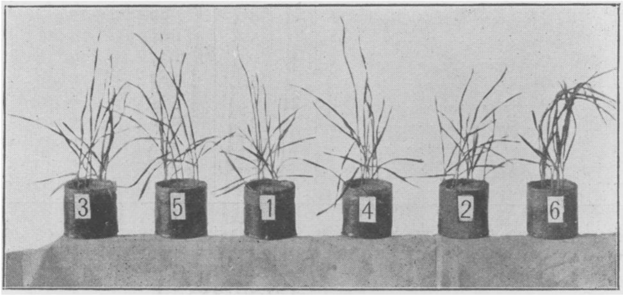

FIG. 13

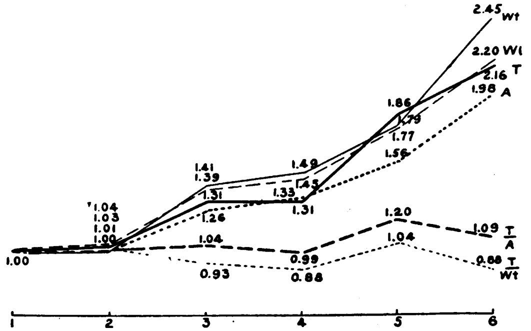

FIG. 14

Series XI.—This is a study of soil extracts made from the soils used in Series X. The plants were grown in bottles, as has been already stated. One bottle containing four plants was used for each culture. The experiment lasted from November 11 to December 1, 1904. The extract was changed every four days, and the transpiration was taken at the same intervals, beginning November 15. The plants were about three days old when placed in the bottles, the seeds having been germinated in sand. The data are given in the table.

A photograph of the series is given in *fig. 15*, and curves in *fig. 16*. It will be observed that the criteria other than transpiration dis-

DATA FOR SERIES XI.

Soil extract	Culture no.	Total transpiration (T)	Green weight leaves (Wl)	Green weight of tops (Wt)	$\frac{T}{A}$	$\frac{T}{Wt}$
Takoma soil	1	41.9	1.07	1.45	0.61	28.9
Cecil clay poor	2	54.9	1.09	1.44	0.75	38.1
Leonardtown loam poor	3	63.8	1.47	1.917	0.70	33.2
Cecil clay good	4	70.8	1.40	1.918	0.80	36.9
Leonardtown loam good	5	75.8	1.70	2.35	0.76	32.3
Garden soil	6	111.6	1.90	2.78	0.96	40.1

agree with the latter in the relation of cultures 3 and 4. By transpiration the soil of 4 is considerably better than that of 3, but by the other criteria it is a trifle poorer. Besides this discrepancy there appears a rather marked disagreement between the difference between 1 and 2 and that between 5 and 6. Comparing this set of curves with those of Series X, we find that the order of arrangement of the soil extracts (by transpiration) differs in one point from that of the soils themselves. By the soils, Cecil clay poor stands lower than Takoma soil, while by extracts this is reversed. However, by all four criteria these two are practically equivalent in the former series, and the same is true in the latter by all criteria but transpiration.

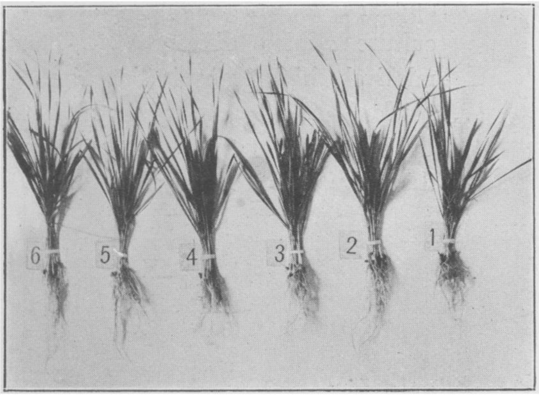

FIG. 15

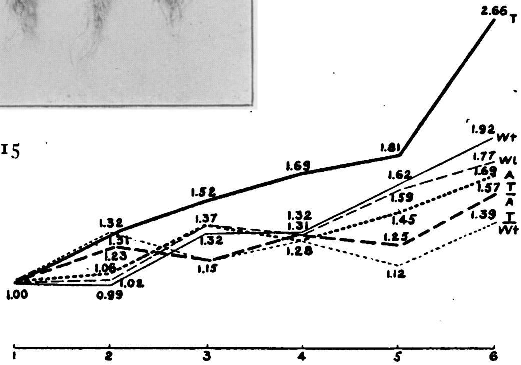

FIG. 16

Transpiration both per unit area and per gram of tops increases quite markedly with the increasing fertility of the extract.

Series XII.—This consists of duplicates of cultures 1, 2, 4, and 6 of Series XI. The cultures were carried on at the same time as were those of the former series. One bottle, containing four plants, was used for each culture. Leaf area was not determined. The curves are given in *fig. 17*.

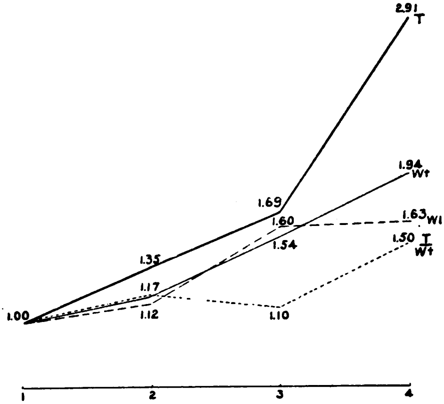

FIG. 17

From them it is seen that the greatest discrepancy between weight and transpiration in Series XI (that occurring in culture 4) does not appear here, and the discrepancy in culture 2 also disappears. The relatively high transpiration of the garden soil is again exhibited, but by both weight and transpiration the cultures fall in the same order, and this is the order obtained in the preceding series. Regarding the relation of Takoma soil to Cecil clay poor, it may be that the deleterious properties of the former are more pronounced in aqueous extract than in the soil itself.

Series XIII.—This consists of five different nutrient solutions. No. 1 is a solution of the necessary salts which had already had wheat plants growing in it for twenty days. No. 2 is the same with one part per million pyrogallol added. No. 3 is the same but with ten

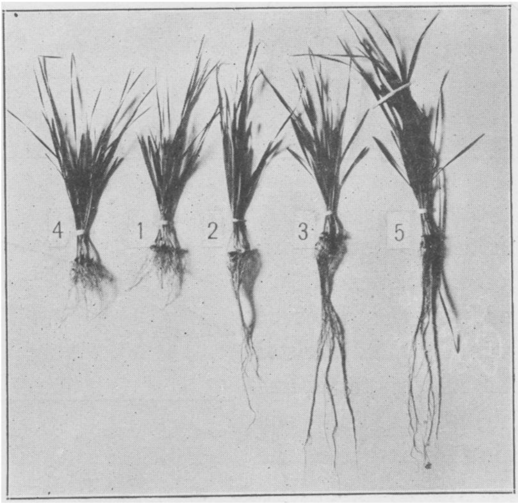

FIG. 18

times as much of the chemical. No. 4 is a nutrient solution exactly like no. 1 but freshly made. No. 5 is the used nutrient solution with manure extract added. The cultures lasted from October 11 to November 8, 1904. The transpiration was taken for 17 days, from October 22 to November 8.

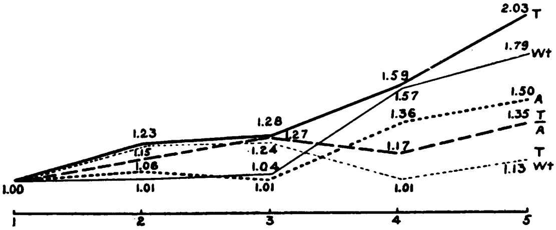

FIG. 19

A photograph of the series is shown in *fig. 18*, and curves are given in *fig. 19*. The first three cultures show practically the same weights and leaf areas, and nos. 2 and 3 show about equal transpirations. The transpiration numbers for nos. 2 and 3 are somewhat greater than that for no. 1. Nos. 3, 4, and 5 show about the same relation to each other by all three criteria, transpiration, weight, and area. In other words, the transpiration is surprisingly high in the two cultures containing pyrogallol. In some way this substance usually accelerates growth of roots, and this may explain the discrepancies above referred to. The question here brought up will be deferred to a future time.

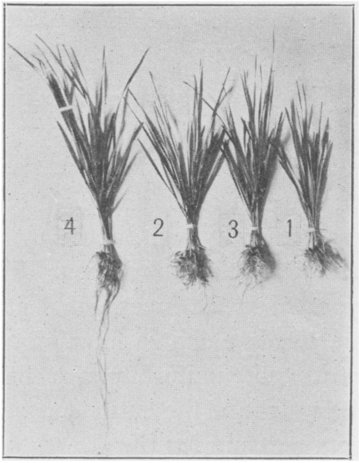

FIG. 20

Series XIV.—This consists of soil extracts all made by the method described by WHITNEY and CAMERON (*loc. cit.*). No. 1 is an extract of the poor Takoma soil used in Series I, etc., but which had been used for the growth of wheat before for a period of twenty days. No. 2 is of the same extract freshly made with addition of one part per million pyrogallol. No. 3 is the same as the last without pyrogallol; and no. 4 is similar, but with addition of manure extract instead of the chemical. The period is the same as that for Series XIV.

The photograph for this series is given in *fig. 20*, and the curves in *fig. 21*. The three criteria arrange the cultures in the same order, although by transpiration the difference between nos. 2 and 3 is emphasized. Transpiration per unit area increases somewhat with the fertility of the solution; while that per gram is practically uniform throughout the series. The former of these ratios thus appears to vary in the opposite direction from that shown in certain of the soil series already described. It may be that the presence of a superabundance of water about the roots raises the transpiration per gram and per unit area above what it would be if the roots were in soil.

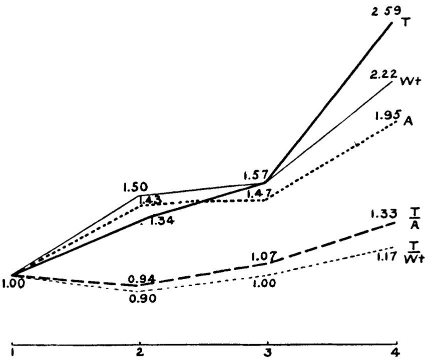

FIG. 21

CONCLUSION.

From the experiments which have been described the conclusion seems evident that total transpiration of wheat plants grown in various media is as good a criterion for comparing the relative growth in these media as is the weight of the plants. That these two criteria vary generally with the weight and area of the leaves gives the explanation for this conclusion. The facts are made clear that, for the types of media investigated at least, the amount of transpiration is practically a simple function of the leaf surface; and that this latter varies quite uniformly with the leaf weight, which in turn varies with the weight of the entire tops. Thus total transpiration appears to be a measure for the growth of the plant. With some series there seems to be a slight variation in the ratios of transpiration to weight and to area respectively, according to the nature of the medium; but these variations are so small when compared with those of their component terms, and lack uniformity in the different series to such a degree that they are practically negligible in the comparison of the cultures. It thus appears that the nature of the soil or solution in which the roots are grown has little or no influence on those structural and physiological properties of the leaves which control the amount of water lost per unit of leaf surface. The water loss per unit area of leaves is practically uniform throughout the different treatments; therefore the variations in total transpiration exhibited are due not to any difference in structure or activity of the leaves, but simply to the differences in extent of leaf surface developed.

In making use of this criterion of transpiration for the comparison of different nutrient media, it must be borne in mind that, as in all other biological experimentation, there will occur unexplained variations, and the truth must be attained by the summation of the results of a number of experiments. Many of the unexplained discrepancies of the experiments just described might not have occurred had the number of plants used been larger. The individual variation among wheat plants is found to be great, so that the larger the number of plants used the nearer would the result approach the true average.

Also, it must be remembered that if total transpiration is decreased by temperature, atmospheric conditions, etc., the different members of a series will approach each other in the amount of water lost; were transpiration checked completely, all the members would agree. It is thus necessary to have good conditions for evaporation from the leaves where such experiments are carried on, in order to magnify the differences in transpiration and keep them well above the limits of experimental error.

The method for comparison of plant growth here provisionally established for wheat is found also to hold for the grasses generally. This doubtless rests on the fact that the leaves of these plants are linear and of continuous basal growth. Whether or not it can be adapted to other groups of plants is not yet determined.

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